

Solutions Network Formulation Report

Forecasting Plant Productivity and Health Using Diffuse-to-Global Irradiance Ratios Extracted from the OMI Aerosol Product

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1. Candidate Solution Constituents

- a. Title: Forecasting Plant Productivity and Health Using Diffuse-to-Global Irradiance Ratios Extracted from the OMI Aerosol Product
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- c. Identified Partners: U.S. Department of Agriculture's ARS (Agricultural Research Service), North Carolina State University, Purdue Climate Change Research Center, Cooperative Institute for Research in the Atmosphere at Colorado State University
- d. Specific DST/DSS: ARS Plant Science Research Unit's Ecological, Physiological, and Genetic Aspects of Global Climate Change Impacts in Field Crop Systems
- e. Alignment with National Application: Agricultural Efficiency, Air Quality
- f. NASA Research Results – Table 1:

Missions	Sensors/Models	Data Product
Aura	OMI ¹	OMAERUV (aerosol extinction and absorption optical depth)
GSFC ²	OMI radiative transfer model	Diffuse-to-global irradiance ratio
GSFC/University of Maryland	6S ³ radiative transfer model	Diffuse-to-global irradiance ratio

¹OMI: Ozone Monitoring Instrument; ²GSFC: Goddard Space Flight Center; ³6S: Second Simulation of the Satellite Signal in the Solar Spectrum

- g. Benefit to Society: Improved monitoring and forecasting of crop productivity and health

2. Abstract

Atmospheric aerosols are a major contributor to diffuse irradiance. This Candidate Solution suggests using the OMI (Ozone Monitoring Instrument) aerosol product as input into a radiative transfer model, which would calculate the ratio of diffuse to global irradiance at the Earth's surface. This ratio can significantly influence the rate of photosynthesis in plants; increasing the ratio of diffuse to global irradiance can accelerate photosynthesis, resulting in greater plant productivity. Accurate values of this ratio could be useful in predicting crop productivity, thereby improving forecasts of regional food resources. However, disagreements exist between diffuse-to-global irradiance values measured by different satellites and ground sensors. OMI, with its unique combination of spectral bands, high resolution, and daily global coverage, may be able to provide more accurate aerosol measurements than other comparable sensors.

3. Detailed Description of Candidate Solution

a. Purpose/Scope

The rate of photosynthesis in plants is significantly influenced by the amount and type of irradiance incident on the plants. Increasing the ratio of diffuse irradiance to global irradiance can accelerate photosynthesis, thereby increasing productivity (Roderick et al., 2001). Studies by Niyogi et al. (2004) have indicated that an increase in diffuse radiative flux correlates with higher CO₂ flux (CO₂ flux is proportional to photosynthetic activity) for broadleaf deciduous and mixed forests and crops such as winter wheat, soybean and corn. In contrast, a higher diffuse radiative flux correlated with a lower CO₂ sink in grasslands. It is thought that these differences may be due in part to differences in leaf shape and shading: spherical leaf shapes have less shading in diffuse light than blade shaped leaves as in grasses and therefore may experience greater overall irradiance, leading to a higher photosynthesis rate. Aerosol loading has been identified as a major contributor to increased diffuse irradiance (Kim et al., 2005; Kaufman et al., 2002). Measurements of diffuse-to-global irradiance ratio may be useful for predicting plant productivity. The components of irradiance can be retrieved from measurements by satellite sensors and surface instrument networks and can be calculated with atmospheric models (Cavazzoni, 2006; Rivington et al., 2002). However, significant disagreements have been observed between the satellite values, surface values, and model results (Kim et al., 2005; Matsui et al., 2004). Because of these disagreements, the sparse distribution of surface sensors, and the enormous variation of atmospheric aerosols over time and space, more accurate satellite-based measurements of atmospheric aerosol properties are needed from which the diffuse fraction of irradiance can be retrieved. Satellite observations from OMI can be used to collect accurate data on atmospheric aerosols, from which information on diffuse versus global irradiance can be extracted. This information could then be used to predict photosynthesis rates and hence the expected plant productivity for crops or other vegetation in a selected region. These irradiance measurements could be invaluable for predicting vegetative health and plant recovery rates following a natural disaster, such as a volcanic eruption (Robock, 2005) or a forest fire (Kanniah et al., 2006), or resulting from anthropogenic air pollution.

b. Identified Partners

The ARS is the USDA's (U.S. Department of Agriculture's) chief scientific research agency and as such would make an appropriate potential partner. The Plant Science Research Unit of the ARS is based at North Carolina State University in Raleigh, NC. Scientists in this unit conduct research to determine how atmospheric contaminants and climate change affect plant growth, development, and yield (ARS, 2007a). In addition, two other university groups have been identified as potential partners. The Purdue Climate Change Research Center (PCCRC, 2004) is conducting research to determine how changes in aerosols, stratospheric ozone, and clouds affect the distribution of ultraviolet radiation reaching plants. The Cooperative Institute for Research in the Atmosphere, located at Colorado State University (CIRA, 2007), conducts research on climate, applications of satellite observations, air quality, and visibility.

Experimental studies have demonstrated that diffuse-to-global irradiance ratio can have a significant effect on photosynthesis rate. While no formal DSSs currently require accurate values of this ratio, models are being developed that will incorporate diffuse-to-global irradiance ratio. The USDA ARS "Ecological, Physiological, and Genetic Aspects of Global Climate Change Impacts in Field Crop Systems" project is performing research and assessments that focus primarily on ozone but also focus on the effect of diffuse irradiation on crop productivity (ARS, 2007b). In the context of the Applied Sciences Program, DSTs (decision support tools) include assessments that serve policy and management decisions.

c. NASA Earth-science Research Results

The satellite platform for OMI is Aura, which was launched in July 2004. Aura has a 6-year design life and is part of the NASA Afternoon Constellation (the “A-train”). The satellite is in a sun-synchronous polar orbit crossing the equator at 1:45 p.m. The orbit has a period of 100 minutes and a repeat cycle of 16 days.

The OMI sensor is a hyperspectral pushbroom imager with 740 channels over a spectral range of 0.27–0.50 μm . The nominal ground resolution is 13 x 24 km, which can be zoomed to 13 x 13 km for detecting and tracking urban-scale pollution sources. The temporal resolution is once per day. The OMI aerosol product containing extinction and absorption optical depth is of particular interest. These data have recently become publicly available (Ahmad et al., 2005; GSFC, 2006). The aerosol product provides daily global near-real-time coverage.

The spectral range of OMI gives it the unique ability to distinguish between aerosols that absorb light and those that do not (Stammes, 2002). This distinction is important because aerosols are major contributors to diffuse irradiance: the type of aerosol influences the ratio of diffuse-to-global irradiance (Kim et al., 2005; Kaufman et al., 2002). Smoke and dust particles both absorb and scatter sunlight, thereby increasing the diffuse component of irradiance but reducing the global irradiance. Sulfate aerosols, however, tend to scatter but not to absorb sunlight, increasing the diffuse component while reducing the global irradiance much less than smoke or dust (Kanniah et al., 2006).

The amount and type of irradiance incident on a plant directly affects the rate of photosynthesis and hence its productivity. An increase in direct irradiance will increase the rate of photosynthesis up to a point, but a further increase saturates the chemical reactions. However, an increase in the ratio of diffuse irradiance to global irradiance can further increase photosynthesis (Roderick et al., 2001).

Direct and diffuse irradiance values have been derived from GOES (Geostationary Operational Environmental Satellite) and compared with surface measurements from the ARM (Atmospheric Radiation Measurement) network (Perez et al., 2001). Measurements have also been made from MODIS (Moderate Resolution Imaging Spectroradiometer) and compared with the AERONET (Aerosol Robotic Network) and IMPROVE (Interagency Monitoring of Protected Visual Environments) sensor networks (Matsui et al., 2004).

However, imagery at high latitudes from geostationary satellites such as GOES can be distorted or unavailable, while data obtained from polar-orbiting satellites varies seasonally because of the large range of day length. These data are also limited by the number of satellites available (Wetzel and Slusser, 2003). Disagreements have been identified between satellite measurements and ground measurements of aerosol properties (Kim et al., 2005; Matsui et al., 2004). Sensors that measure radiance only within the visible and infrared spectrum (such as MODIS) or the ultraviolet spectrum (such as the Total Ozone Monitoring Spectrometer) retrieve only the extinction optical depth and therefore cannot distinguish between absorbing aerosols (smoke and dust) and nonabsorbing aerosols (sulfates). OMI, which measures radiance in both the visible and ultraviolet range, provides enough information to retrieve the absorption optical depth, enabling absorbing aerosols to be distinguished from non-absorbing aerosols. In addition, OMI possesses the capability to distinguish between smoke and dust in certain circumstances (Stammes, 2002).

d. NASA Earth Science Models

Radiative transfer models supported by NASA can be used to calculate diffuse-to-global irradiance ratio. These models include the OMI radiative transfer model, used for retrieving aerosol properties from OMI measurements (Stammes, 2002), and the 6S (Second Simulation of the Satellite Signal in the Solar Spectrum; Vermote et al., 1997).

e. Proposed Configuration’s Measurements and Models

OMI measures aerosol extinction optical depth and single-scattering albedo, from which absorption optical depth is retrieved. Its unique combination of ultraviolet and visible wavelength bands enables differences between absorbing and nonabsorbing aerosols to be identified. Differences between dust and smoke can be determined if the smoke optical depth is less than a value of 2 (very dense haze, smoke, or dust; Stammes, 2002).

The aerosol data products from OMI will provide input data for a radiative transfer model, such as the OMI model (Stammes, 2002) or 6S (Vermote et al., 1997). The radiative transfer model will calculate diffuse-to-global irradiance ratios that will then be incorporated into photosynthesis models which will be used by the USDA ARS photosynthesis assessment DST. The output data will then be used to determine the effect of atmospheric aerosols (expressed in terms of diffuse-to-global irradiance ratio change) on field crop systems. While these photosynthesis models are not yet fully developed, they are expected to become available within 3 to 7 years. The implementation of these models will enhance the ability to predict changes in crop productivity induced by atmospheric aerosol loading variability.

4. Programmatic and Societal Benefits

Plant productivity has been shown to increase as the ratio of diffuse-to-global irradiance is raised as sunlight is scattered by aerosol particles. Atmospheric aerosol loading is highly variable over time and space and can be elevated by anthropogenic activities and by natural events, such as volcanic eruptions, forest fires, and dust storms. If accurate measurements of atmospheric aerosols can be acquired on a regular basis, our ability to forecast diffuse-to-global irradiance ratios and hence to predict plant productivity and health will be improved. In the future, information such as this could be invaluable for predicting the availability of regional food resources for sustaining human populations on Earth. The proposed candidate solution benefits the Agricultural Efficiency and Air Quality National Applications.

5. References

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